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Task Switching After Cerebellar Damage

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The authors of this study investigated task switching following cerebellar damage. The study group consisted of 7 children and adolescents (*M* age = 13.8 years) who underwent surgical removal of a benign posterior fossa tumor. They were tested at a sufficient interval after surgery (*M* lag = 6.13 years) for restoration of normal cognitive skills and intelligence. Although all showed normal learning of the task compared with control participants, when rapid behavioral changes were required (short preparation time), they exhibited behavioral rigidity manifested by enhanced switching cost. These results are in line with another study on serial reaction time with the same patients (A. Berger et al., in press). They have important implications for our understanding of the cognitive sequelae of early cerebellar damage as well as the involvement of the cerebellum in task switching.

Keywords: task switching, executive control, cerebellum, posterior fossa tumor

The idea of frontallike cognitive impairment in cases of cerebellar dysfunction has received considerable interest. Neuronal loops involving the frontal lobe, the cerebellum, and the basal ganglia have been traced (Middleton & Strick, 2000), and functional relationships between the cerebellum and the frontal lobe have been observed in neuroimaging studies (Junck et al., 1988; Kim, Ugurbil, & Strick, 1994). Moreover, there are some reports of individual cases of severe frontallike syndromes following cerebellar damage (Akshoomoff, Courchesne, Press, & Iragui, 1992; Botez-Marquard, Bard, Leveille, & Botez, 2001) and reports of deficits in anticipatory planning, as assessed by the Tower of Hanoi test, in patients with cerebellar atrophy (Grafmann et al., 1992). However, the overall neuropsychological picture with respect to the status of frontal functions in patients with cerebellar lesions is inconsistent (Daum & Ackermann, 1997). This is especially true for the switching aspect of executive functioning. Although cerebellar activation has been observed during performance of the Wisconsin Card Sorting Test (Berman et al., 1995), patients with cerebellar abnormalities usually show no impairment in this task (Daum et al., 1993; Fiez, Petersen, Cheney, & Raichle, 1992). A closer look at the Wisconsin Card Sorting Test reveals that besides the ability to shift attention between modalities, which is known to be impaired in patients with cerebellar damage (Akshoomoff et al., 1992), the test requires several additional cognitive skills. These include the ability to adapt behavior and change it according to feedback, the ability to abstract rules, and the ability to keep track of past choices (e.g., Goldman, Axelrod, Tandon, & Bernet, 1991).

To eliminate the confounding effects of these other factors, researchers introduced the task-switching paradigm, which tests only the switching aspect. Functional MRI studies have shown cerebellar activation during task switching (e.g., Dreher, Koechlin, & Omar Ali, 2002); however, there are as yet no reports on the performance of patients with cerebral damage in the task-switching paradigm.

Task Switching

Although there is no consensus on the definition of executive control functions, most experts would include such functions as updating goal representation in working memory, monitoring con-

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flict and error, optimizing performance in the face of conflicting demands, and changing the ad hoc configuration of mental processes in order to meet task characteristics. All these functions are probably accessed to some degree in the task-switching paradigm (e.g., Monsell & Driver, 2000). A typical task-switching paradigm involves two or more reaction time (RT) tasks performed on the same set of target stimuli: for example, switching between color and letter tasks, performed on colored letters (Fagot, 1994), or switching between odd–even and vowel–consonant judgments, performed on digit–letter pairs (e.g., Rogers & Monsell, 1995).

Task switching is associated with a number of highly replicable phenomena. Studies have shown that performance is better in trials involving a task repetition rather than a switch (e.g., Rogers & Monsell, 1995). This is termed the *task-switching cost* (or *task-repetition gain*). Performance is also better when the experimental block does not involve any task switching than when the blocks involve switching with task repetition. This effect is called the *task-mixing cost* (Fagot, 1994; Kray & Lindenberger, 2000; Los, 1996, 1999; Meiran, Chorev, & Sapir, 2000). Finally, performance is better in trials in which the rules for both tasks point to the same physical response as the correct one (congruent trials) than in trials in which the rules point to conflicting responses as the current ones (incongruent trials; Meiran, 1996).

The literature is currently divided between two major schools of thought on the mechanism underlying task switching. One camp emphasizes the change in processing configuration during switching and its role in switching cost (e.g., Mayr & Kliegl, 2000; Meiran, 1996; Rogers & Monsell, 1995; Rubinstein, Meyer, & Evans, 2001). The other camp emphasizes interference from processing in preceding trials, a form of negative transfer (e.g., A. Allport & Wylie, 1999; D. A. Allport, Styles, & Hsieh, 1994; Mayr & Kliegl, 2000; Waszak, Hommel, & Allport, 2003; Wylie & Allport, 2000). It is possible that the positive effect of reconfiguration overcomes the detrimental effect of proactive interference, thereby resolving this controversy (e.g., Meiran et al., 2000).

The precise reason for the switching effect notwithstanding, most authors agree that the task-switching paradigm requires some form of what is loosely described as *cognitive flexibility,* that is, either the ability to quickly disengage from and eliminate the detrimental effects of proactive interference or the ability to quickly prepare for a new task, or both. The task-switching paradigm measures this aspect of flexibility in a much purer form than more traditional tests, such as the Wisconsin Card Sorting Test.

Our Sample

Two previous reports (Berger et al., in press; Sadeh et al., 2005) described a group of children and adolescents who underwent surgical removal of a benign posterior fossa tumor (PFT) during childhood. They were tested several years after surgery to allow time for recovery of brain plasticity and functions. The sample was homogeneous in terms of the nonmalignant nature of the tumors, such that none of the participants underwent chemotherapy or cranial radiation therapy, and all were attending regular schools. Neurologic examination on entry to the study revealed only one case of gait ataxia and one case of clumsiness; there were no other gross or fine neurologic abnormalities. Extensive neuropsychological assessment yielded four major findings: (a) intelligence within the average range in all cases; (b) slight difference from a matched control group in tests involving memory of verbal stimuli, such as the Digit Span subtest of the Wechsler Intelligence Scale for Children—Revised (WISC–R; Wechsler, 1974), but not in the Corsi block (Sadeh et al., 2005); (c) a trend toward slower responses, compared with control participants; and (d) no clear signs of frontal deficits. The patients were tested with a computerized serial reaction task (Berger et al., in press). The results indicated that they were able to learn the task at a normal rate, but in contrast to the control group, their RTs and accuracy were markedly affected when the sequence was replaced by a random pattern, indicating a more rigid performance with overcommitment to the repeating sequence.

Because their impairment became noticeable only when there was an abrupt change in sequence, in the present study we sought to further examine their ability to adapt to changes in the task and to switch between tasks. The task-switching paradigm is an experimental computerized task specifically designed to test this ability. We succeeded in recruiting 7 of the 8 patients tested previously with the serial reaction task. We assumed that the performance of these patients in the task-switching paradigm would contribute to our understanding of cognitive sequelae following early cerebellar damage. As this task had not yet been used in patients with cerebellar damage, we hoped our findings would also shed light on the possible involvement of the cerebellum in task switching.

Method

Participants

The participant population was divided into two groups: a PFT group and a matched, healthy control group. The PFT group consisted of 7 children and adolescents who had a PFT during childhood. The tumor type was either astrocytoma Grade I, astrocytoma Grade II, pilocystic astrocytoma, or nonmalignant cystic. None of the participants underwent chemotherapy or cranial radiation therapy. Ages at surgery ranged from 1 to 11 years ($Mdn = 7.9$ years), and ages at the time of the study ranged from 9 to 17 years ($Mdn = 14.2$ years). The interval between surgery and testing was at least 2.5 years to allow for brain plasticity and recovery of function (average = 6.13 years, $SD = 2.9$ years). Two of the participants underwent more than one operation (see Table 1). For these 2 participants, age at surgery was calculated from the first surgery, and time of testing from the second surgery. None of the patients had transient postoperative mutism, a well-known sequela found in about 8.5% of cases of PFT resection in children (Pollack, 1997).

MRI was performed before and after surgery in all cases to assess the damage induced in the posterior fossa by the tumor and its removal. Every scan was independently evaluated by an expert neuroradiologist. Table 2 includes a detailed description of the extent of damage to the cerebellum in the participants, and Figure 1 illustrates the typical localization of the damage.

The control group consisted of 7 healthy children with no neurologic history, matched to the PFT group for sex, age, education, and performance on four subtests of the WISC–R that estimate performance, intelligence, and socioeconomic background and level. All children in both groups attended regular schools.

Apparatus and Stimuli

All testing was performed with an IBM clone computer (Intel Pentium I Processor, 233 MHz), equipped with a DOS operating system and

Table 1
Clinical Data on the Posterior Fossa Tumor Group

				Age (years)				
Patient	Sex	VIQ	PIQ	At 1st surgery	At 2nd surgery	At first test	Years after last surgery	Neurological signs
1	Boy	108	118	10.8	None	16.8	6.0	+
2	Boy	116	122	8.9	None	12.9	4.0	−
3	Boy	114	123	3.9	None	14.9	11.0	−
4	Boy	101	112	6.5	6.6	9.1	2.5	−
5	Boy	110	128	10.0	None	16.8	6.8	−
6	Girl	105	100	1.0	5.8	14.2	8.4	+
7	Girl	101	118	7.9	None	12.1	4.2	−

Note. VIQ = Verbal IQ estimation (based on four WISC–R subtests); PIQ = Performance IQ estimation (based on four WISC–R subtests); + = presence of any type of neurological sign at the time of testing; − = absence of any type of neurological sign at the time of testing; WISC–R = Wechsler Intelligence Scale for Children—Revised.

software written in MEL (Meiran, Gotler, & Perlman, 2001; Schneider, 1988). Responses were keyed in with a standard keyboard. Time of response (in milliseconds) and accuracy were automatically recorded by the computer. The stimuli were drawn in white on a black background and consisted of the graphic symbols in the extended ASCII code. A 2 × 2 grid was presented at the center of the screen and subtended a visual angle of approximately 3.4° (width) × 2.9° (height). The target was a smiling-face character (ASCII code 1), which subtended approximately 0.3° (width) × 0.5° (height). The arrowheads (ASCII codes 16, 17, 30, and 31) subtended approximately 0.3° × 0.3° and were positioned 0.7° from the end of the grid (visual angles were computed on the assumption of a 60-cm viewing distance).

Procedure

In the version of the task-switching paradigm used here (Meiran et al., 2001), the 2 × 2 grid (creating four squares) at the center of the screen served as the frame for fixation. After the fixation period, two arrowheads (instructional cue) appeared vertically or horizontally on both sides of the grid, indicating which one of two tasks was to be used in the next trial: Task A (up–down discrimination, vertical arrowheads) or Task B (right–left discrimination, horizontal arrowheads). The target stimulus (smiling face) then appeared in one of the four squares. The interval between the appearance of the instructional cue and the target stimulus (cue–target interval; CTI) was either 116 or 1,016 ms (see Figure 2). This period is sufficient to produce maximal readiness in this paradigm (Meiran et al., 2000). The interval between the response in Trial *N*-1 and the appearance of the instructional cue (arrowheads) in Trial *N* (response–cue interval; RCI) remained constant at 2,032 ms. This interval has been found to be sufficiently long for dissipation of the task set adopted in the preceding trial; extending it further does not reduce the switching cost (Meiran et al., 2000). The task, target location, and CTI were selected at random at each trial. Hence, the instructional cue did not indicate the upcoming target location, the correct keypress, or the time of target onset.

The keyboard was shifted to the left in order to align the right numerical keys with the center of the screen. Participants were asked to respond as quickly as possible by using the index fingers of both hands to press the key corresponding to the target position and to the task used. A 100-ms beep of 400 Hz signaled an error. We used a bivalent response setup in which the same set of physical keys was used in both tasks (e.g., the upper left key indicated "up" in the up–down task and "left" in the left–right task). Half the participants used keys 1 and 9 on the right-numerical keyboard (for up/left and down/right responses, respectively), and half used keys 3 and 7 (see Figure 2).

The test was composed of six blocks: five mixed-task blocks (wherein trials involving Task A and Task B were intermixed), followed by one single-task block (wherein the sequence of trials involved the same task, either A or B). The first (mixed-task) block was a practice block (20 trials), and the other five were the test blocks (80 trials each). The single-task block always came after the mixed-task blocks because introducing the single-task condition first might have made the practice task easier than the

Table 2
Extent of Damage to the Cerebellum in the Posterior Fossa Tumor Group

	Damage to cerebellar hemisphere			Damage to specific structures			Estimated size of damage (cm)		
Patient	Vermis	Right	Left	Den	Corpus med	I Ped	AP axis	ML axis	CC axis
1	2	3	−	+	+	−	2.0	1.5	2.0
2	1	3	−	−	−	−	1.2	1.0	2.5
3	−	2	−	−	−	−	1.0	0.8	0.5
4	3	−	−	+	+	+	0.6	2.5	1.8
5	1	1	−	−	−	−	2.6	0.8	2.5
6	2	3	1	+	+	−	3.5	3.0	3.5
7	3	−	−	−	−	−	1.0	1.2	1.2

Note. Damage: 1 = less than 50%, 2 = more than 50%, 3 = diffuse atrophy, − = no damage, + = damage; Den = dentate; med = medullaris; I Ped = inferior peduncle; AP = anterior–posterior; ML = mediolateral; CC = craniocaudal.

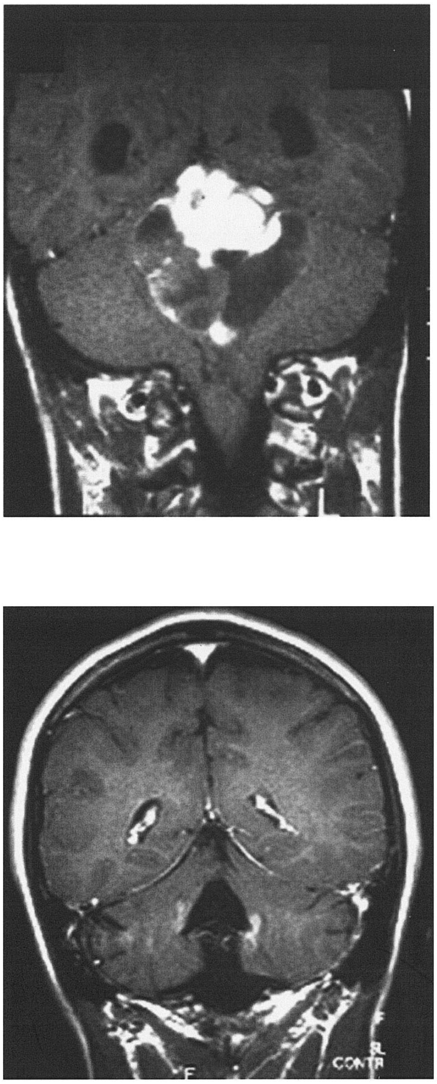

Figure 1. Representative coronal MRI slice from a patient with a posterior fossa tumor before (top) and after (bottom) the surgery.

unpracticed ones. Half the participants performed Task A in the single-task condition, and half performed Task B.

Analysis

All data analyses were done as described in the study of Meiran et al. (2001). The following trials were excluded from the analysis: the first (practice) block, trials in which the RT exceeded 5 s, trials in which the response was erroneous, and trials immediately following an error. The last (single-task) block was divided into 10 miniblocks (8 trials each) for analysis. In all analyses, quartiles (Q; Q_1–Q_3) were included as dependent variables in addition to the medians in order to increase the statistical power and to identify possible differential effects between fast and slow responses (e.g., De Jong, 2000). An analysis of variance with repeated measures was done for RT only, as error rates were extremely low (zero in most conditions), which is characteristic of this specific task-switch paradigm. Three different analyses were conducted (Meiran et al., 2001), each testing a different aspect of performance within the paradigm.

Analysis 1. When the single-task condition follows the mixed-task condition, initial performance is relatively poor, and it resumes normal single-task level only after a few dozen trials. This effect is termed *fadeout* (Mayr & Liebscher, 2001). Accordingly, Analysis 1 included all experimental blocks except the first two miniblocks of the single task that appeared immediately after the last mixed-task block. This analysis was intended to identify the usual effects of the task-switching paradigm, such as congruency and switching. The within-subjects independent variables were Q (Q_1, Q_2 = median, Q_3), CTI (1 = short, 2 = long), switch (Sw; 1 = switch, 2 = no switch, 3 = single), congruency (1 = incongruent, 2 = congruent), and response repetition (RR; 1 = different, 2 = same).

Analysis 2. This analysis was done on the mixed-task blocks only (Blocks 2–5) and was intended to examine the effects of practice in the mixed-task condition. Meiran (1996) and Meiran et al. (2000) found that with a short CTI switching, cost was reduced by similar amounts of practice. The within-subjects independent variables were Q (Q_1, Q_2, Q_3), CTI (1 = short, 2 = long), Sw (1 = switch, 2 = no switch, 3 = single), and block (1–4).

Analysis 3. This analysis included all the experimental blocks except the first two miniblocks of the single task, which appeared immediately after the last mixed-task block (as in Analysis 1). Each of the four mixed blocks in this analysis were also divided into two miniblocks, and the difference in mean RT between the mixed and single blocks was compared within groups. This analysis allowed us to examine the fadeout effects following switching from the mixed to the single condition. The within-subjects variables were Q (Q_1, Q_2, Q_3) and miniblocks (1–8 = mixed, 9–16 = single).

Results

The significant effects involving group are discussed in detail below. The full list of all significant effects ($p < .05$, highlighted in bold) and marginal effects ($.05 < p < .08$, not highlighted) are presented in Tables 3–5, which can be found on the Web at http://dx.doi.org/10.1037/0894-4105.19.3.362.supp.

Analysis 1

There were two triple interactions involving group. The first was CTI × Sw × Group, $F(2, 24) = 4.72$, $p < .05$. The difference within this interaction in the group gap in switching cost between the short and long CTI ([A–C] to [B–D]; see Figure 3) was significant, $F(1, 12) = 5.49$, $p < .05$. This finding indicates that the switching cost was larger for the PFT group than for the control group when there was insufficient time for preparation.

The second interaction was Q × Congruency × Group, $F(2, 24) = 3.73$, $p < .05$. The simple interaction of Q × Congruency was significant only for the PFT group, $F(2, 24) = 9.89$, $p < .01$ (for the control group, $F < 1$). Therefore, further analysis of this interaction was done for the PFT group only. This difference in the gap in congruency effect between Q_3 and $Q_1 + Q_2$ ([E–F] to [A–B] + [C–D]; see Figure 4) was significant, $F(1, 12) = 14.17$, $p < .01$, indicating that in the PFT group, the congruency effect was greater for the longer RT (Q_3) than for the medium and shorter RTs (Q_1 and Q_2; see Figure 4).

Analysis 2

Only one interaction involving group was significant in this analysis, namely, Q × Block × Group, $F(6, 72) = 2.76$, $p < .05$. The simple interaction of Q × Block was significant only for the

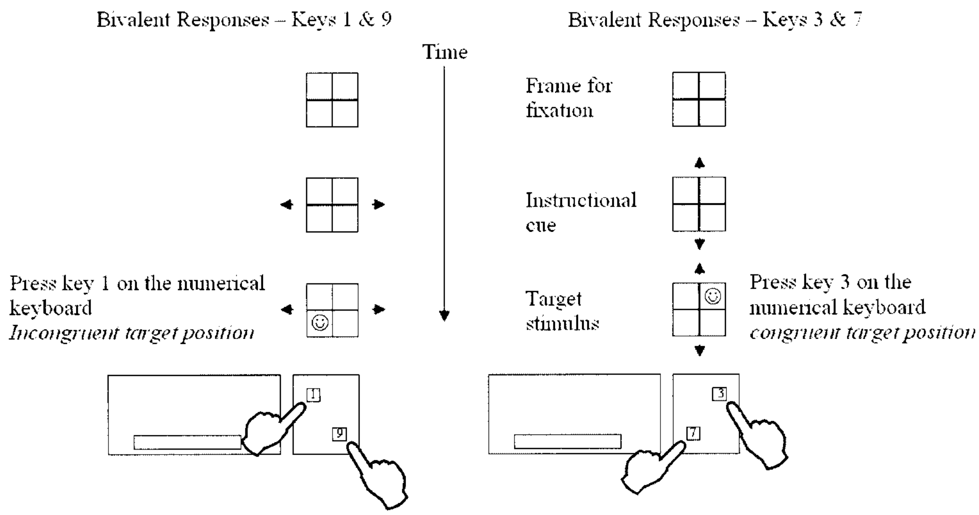

Figure 2. Schematic description of the experimental paradigm.

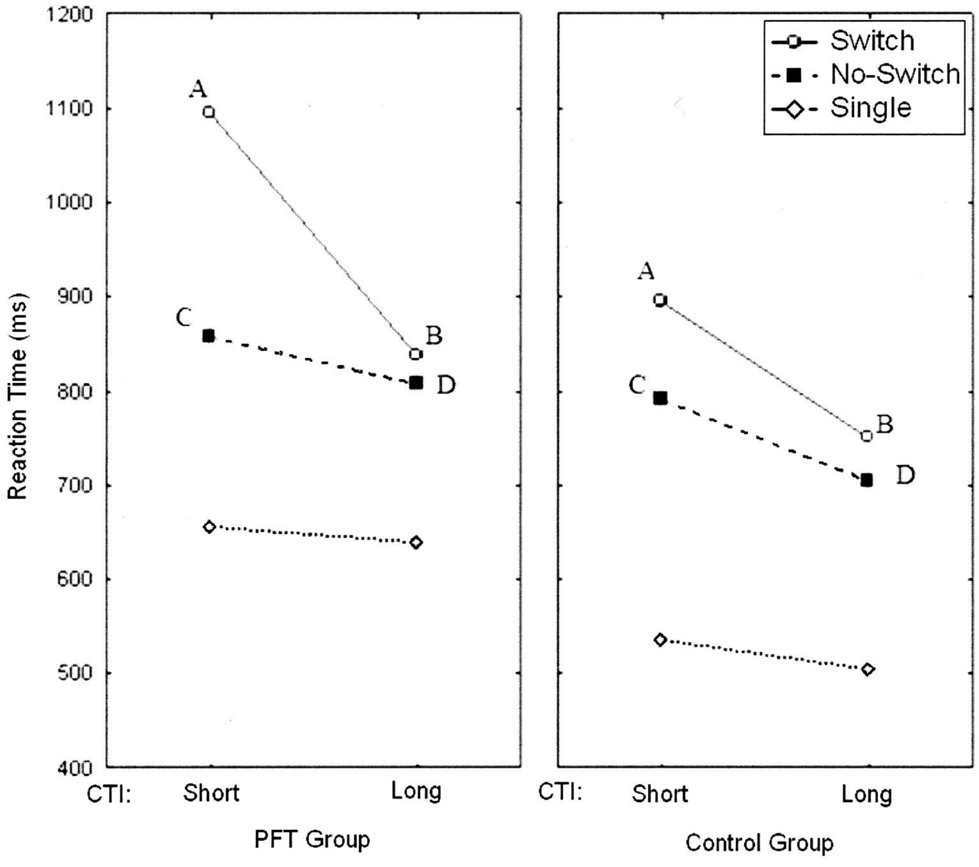

Figure 3. Mean reaction times as a function of cue–target interval (CTI) and switching conditions for the posterior fossa tumor (PFT) and control groups. A–D are used as reference points to aid in comprehension of calculations contained in the text.

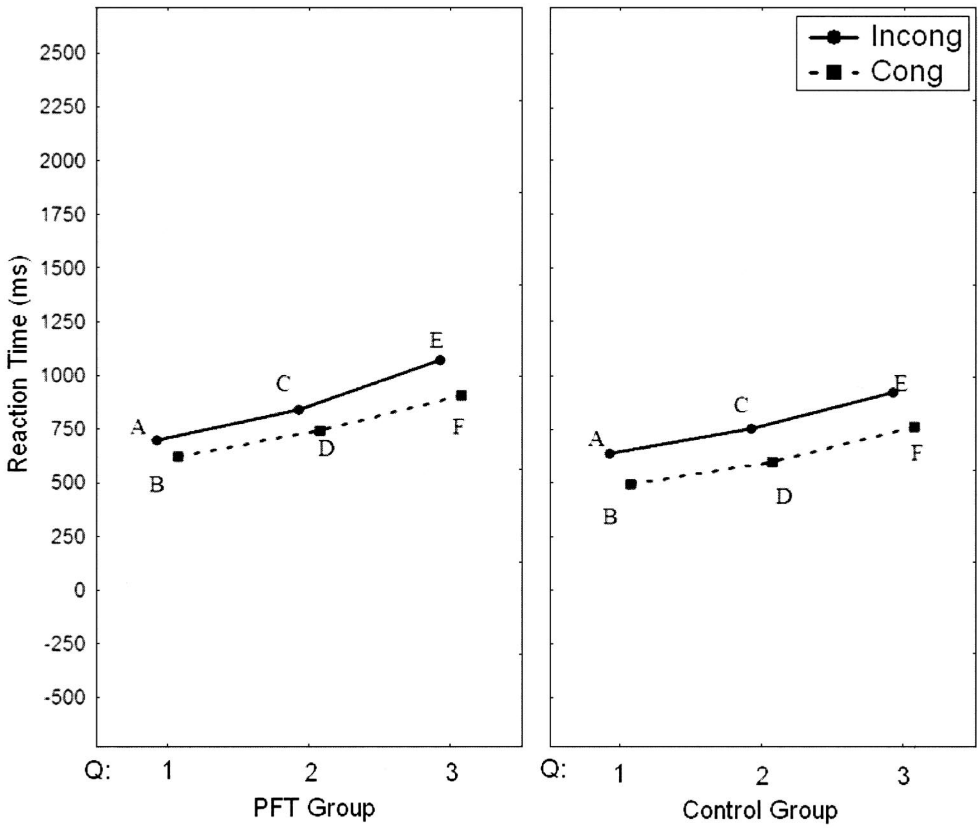

Figure 4. Mean reaction times as a function of congruency condition for the posterior fossa tumor (PFT) and control groups. A–F are used as reference points to aid in comprehension of calculations contained in the text. Incong = incongruent; Cong = congruent. Q = quartile.

PFT group, $F(6, 36) = 3.16$, $p < .05$ (for the control group, $F < 1$). Therefore, follow-up analysis was done for the PFT group only. We found a simple-simple main effect of block only for Q_2, $F(3, 18) = 4.75$, $p < .05$, and for Q_3, $F(3, 18) = 3.74$, $p < .05$, but not for Q_1, $F(3, 18) = 1.77$, $p = .18$, indicating that in the PFT group, the practice effect across blocks was greater for the moderate and long RTs than for the shorter ones (see Figure 5).

Analysis 3

No effects involving group were found in this analysis, indicating normal fadeout in the PFT group. As shown in Figure 6, the “tail” of the single-task blocks looks somewhat noisier in the PFT group than in the control group, and indeed, when the single-task condition without the fadeout blocks was analyzed separately, the Block × Group interaction was significant, $F(7, 84) = 3.76$, $p < .01$

Discussion

In this study, a group of children and adolescents who underwent surgical removal of a benign PFT during childhood was tested with the task-switch paradigm and compared with a matched sample. We found that in spite of their normal learning of the task and relatively intact ability to deal with difficult or demanding ongoing conditions (normal mixing cost), the study children exhibited behavioral rigidity when rapid behavioral changes were required.

These results are consistent with our hypothesis and in agreement with our previous findings in these patients in the serial sequence paradigm (Berger et al., in press). Specifically, the study group differed from the control group in its larger switching cost with the shorter CTI. Moreover, the difficult and/or conflicting situations seemed to yield a statistical effect, especially in the slow RTs, probably because of some trials with exceedingly slow responses, as reflected in the interaction between this effect and the Q variable. Overall, however, the PFT group did not perform slower than the control group, and three of the main effects usually found in the task-switching paradigm, including CTI, Sw, and congruency, were similar in size in both groups (i.e., no interaction with group). The main fourth effect, RR, was marginal. We also found the two typical significant interactions, $Q \times$ CTI $\times$ Sw and $Q \times$ Sw $\times$ Congruency. These findings can be seen in Tables 3–5 on the Web at http://dx.doi.org/10.1037/0894-4105.19.3.362.supp. Of special interest is the block main effect, which reflects practice. Because the Block × Group interaction did not reach significance, we may assume that both groups learned the tasks at a comparable rate.

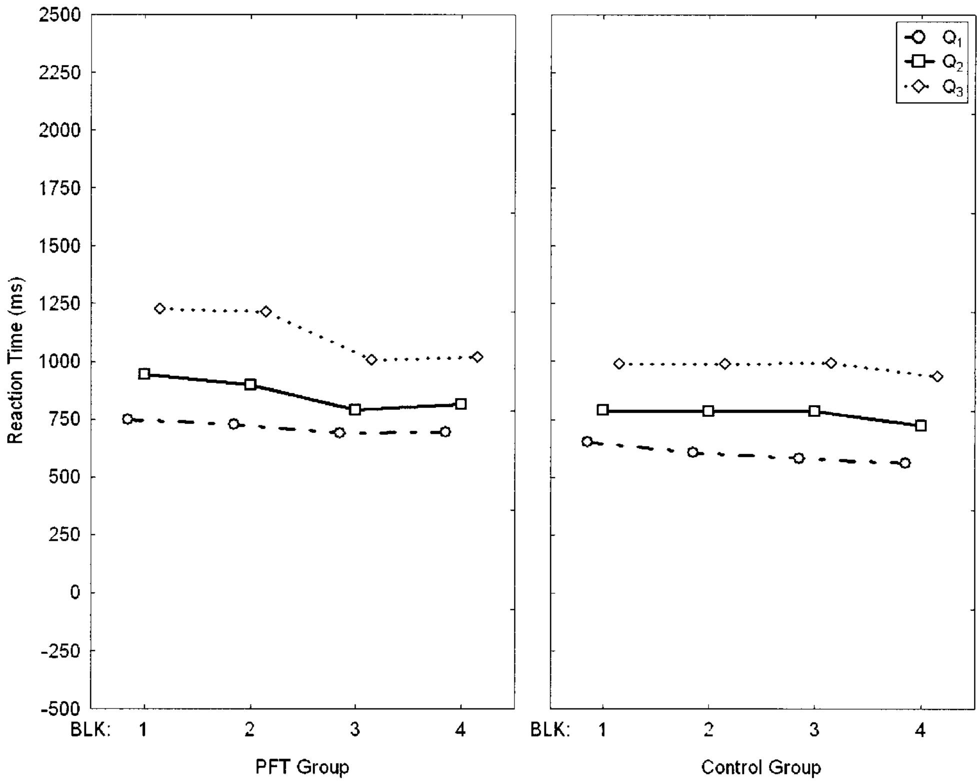

Figure 5. Mean reaction times in the mixed-blocks condition as a function of quartile (*Q*) for the posterior fossa tumor (PFT) and control groups. BLK = block.

Our findings are compatible with recent functional imaging studies indicating some involvement of the cerebellum in task switching (Dreher et al., 2002; Le, Pardo, & Hu, 1998), especially those indicating that the cerebellum is not involved in the switching between attentional sets but in the remapping of responses (response reassignment; Bischoff, Ivry, & Grafton, 2002). Moreover, regarding the localization of the activation within the cerebellum, Dreher et al. (2002) reported activation in both the vermis and the left cerebellar hemisphere when comparing between switch and baseline (single-task) conditions, but only in the left hemisphere when comparing unpredictable and predictable task orders. In our sample, mainly the vermis (in 6 of 7 patients) and right-hemisphere cerebellar were affected by the tumor. Therefore, the impairment in the task-switching task might be related to the vermis damage. Accordingly, the earlier study on this group of participants found overall normal cognitive development, with two isolated deficits: (a) a mild verbal deficit (Sadeh et al., 2005), which is consistent with the localization of the damage in the right cerebellar hemisphere and the vermis (see review of cerebellar involvement in verbal processing in Fiez & Raichle, 1997), and (b) a mild rigidity when there was a need for a rapid change in the behavioral set (Berger et al., in press).

Do patients with PFT show long-term sequelae of frontal deficits? This question is important in light of the tight connections between the cerebellum and the frontal lobe, which apparently lead to frontal hypofunctioning and hypometabolism in adults with cerebellar damage of various etiologies (Akshoomoff et al., 1992; Botez-Marquard et al., 2001). The pattern of results we obtained in the task-switching paradigm was strikingly different from the pattern reported for patients with frontal deterioration (Meiran et al., 2001). Whereas our patients showed normal practice effects but exaggerated switching costs when preparation time was too short, patients with frontal degeneration (Meiran et al., 2001) and frontal focal lesions (Rogers et al., 1998) showed exaggerated mixing and residual and switching costs, but no effects of CTI on switching costs. On the basis of findings in event-related functional imaging studies (Dove, Pollmann, Schubert, Wiggins, & von Cramon, 2000; Dove, Schubert, Pollmann, Norris, & von Cramon, 1999; Moulden et al., 1998; Rubinstein, Evans, & Meyer, 1994), Meiran et al. (2001) suggested that whereas the congruency effect and the residual cost are subserved by prefrontal regions in the task-switching paradigm, the preparatory component is subserved by more posterior areas and is therefore relatively preserved in patients with frontal deterioration. Our results are in line with this distinction: The PFT group showed normal effects in all aspects of the task that, according to Meiran et al. (2001), are mediated by frontal regions and impairment in the aspects that are apparently mediated by nonfrontal regions. In this sense, the present results also agree with the neuropsychological findings of no frontal signs in the same patients in the previous study (Sadeh et al., 2005). We conclude, therefore, that although frontal dysfunction has been reported in cases of cerebellar lesions of various etiologies in

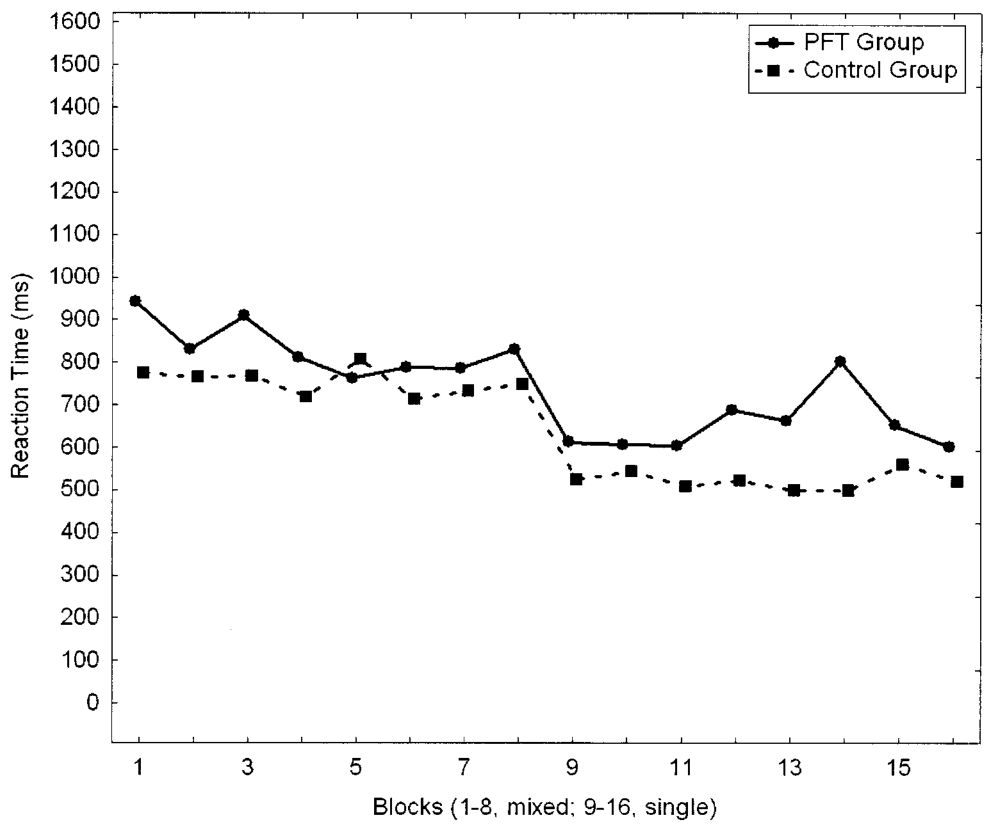

Figure 6. Mean reaction times in the different blocks (all blocks, including fadeout) for the posterior fossa tumor (PFT) and control groups.

adulthood, it is not necessarily found in all cases of cerebellar lesions. More specifically, in patients with cerebellar lesions in childhood who did not have chemotherapy or cranial radiation therapy, there are no signs of long-term impairment of frontal functioning, at least at the behavioral level. Nevertheless, as we did not measure metabolic values in our patients, we cannot rule out the possibility that there is some degree of frontal hypometabolism compensated by other areas in the brain.

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